Machine Performance and 5-year projections

d-Au and pp operations during Run-3 (FY2003)

Projections for Run-4 (FY2004)

5-year projections

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Office of Science U.S. DEPARTMENT OF ENERGY

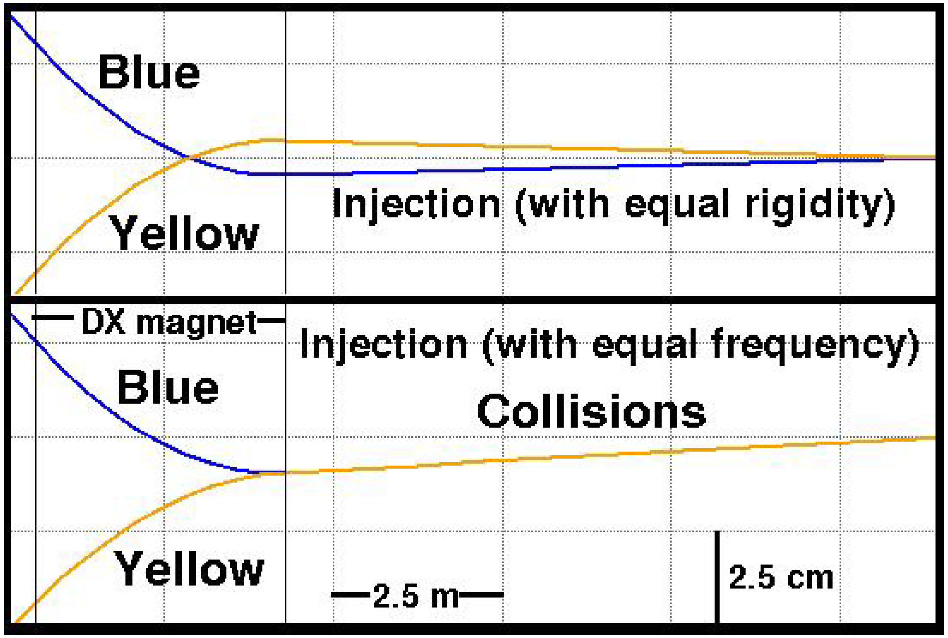
Thomas Roser
RHIC Detector Adv. Committee Meeting
November 22, 2003

Run-3 Achievements

- First asymmetric d-Au collisions with equal-energy injection and acceleration
- Additional bunch merge for deuteron: two Tandem pulses per RHIC bunch
- $\beta^* = 1$ meter at both PHEINX and STAR for proton-proton collisions
- Commissioning of eight new spin rotators to give longitudinal polarization at PHENIX and STAR
- 50 % polarization at AGS extraction; 35 % polarization at 100 GeV
- Commissioning of new AGS polarimeter and first polarization measurements during the AGS and RHIC acceleration ramps

Deuteron-Gold Collisions in RHIC (RUN-3)

- Important comparison measurement: will not produce quark-gluon plasma
- Collisions at 100 GeV/nucleon requires 20% different rigidities
- Use two Tandems; add. bunch merging in Booster:
  1.1×10^{11} d/bunch, $\varepsilon[95\%] = 12\ \pi\ \mu m$; 0.7×10^{9} Au/bunch, $\varepsilon[95\%] = 10\ \pi\ \mu m$
- Initial injection with equal rigidity failed because of beam loss from modulated beam-beam interactions during acceleration ramp
- Injection and acceleration with same energy was successful.



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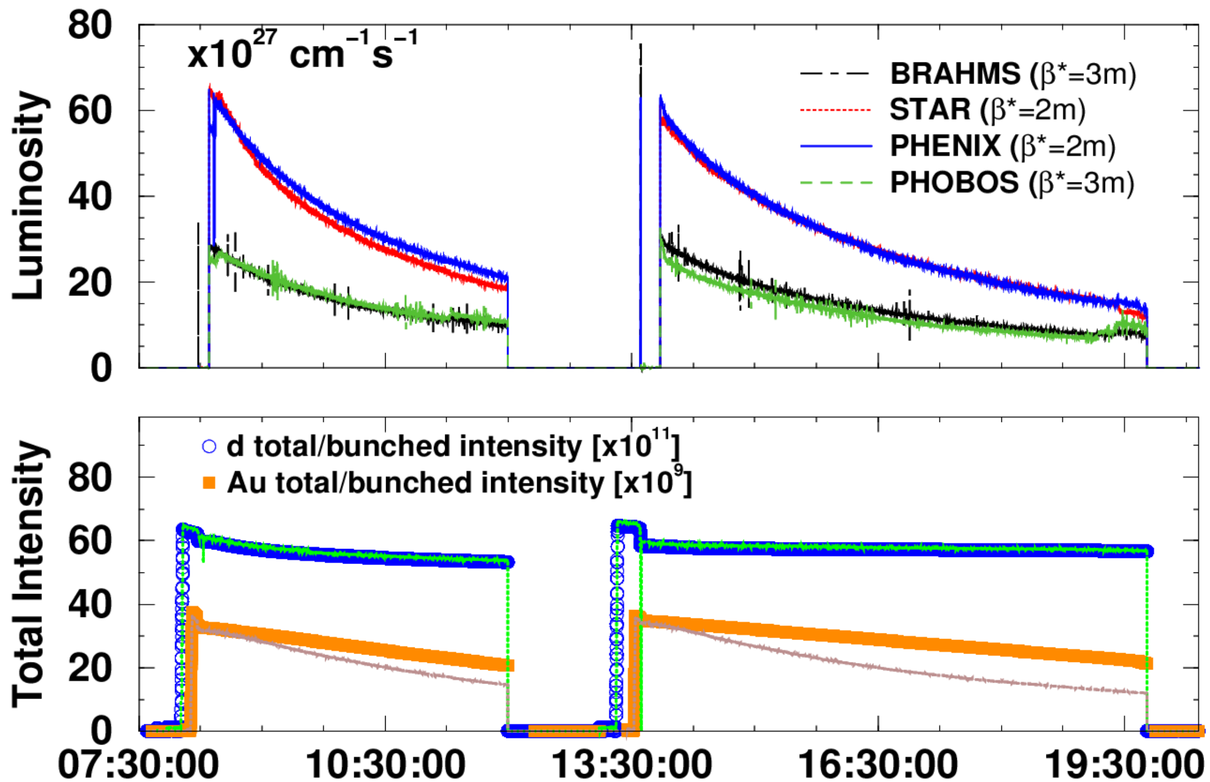
“Typical” Deuteron-Gold Stores

- Vacuum pressure rise limits total charge (both beams) to 10^{13} (~ 56 bunches)
- Transverse instability cured by crossing zero-chromaticity before transition
- Need Landau cavities to avoid coherent longitudinal oscillation during acceleration.
- Fixed noise in 200 MHz system to give good deuteron lifetime
- Intra-beam scattering affects gold beam



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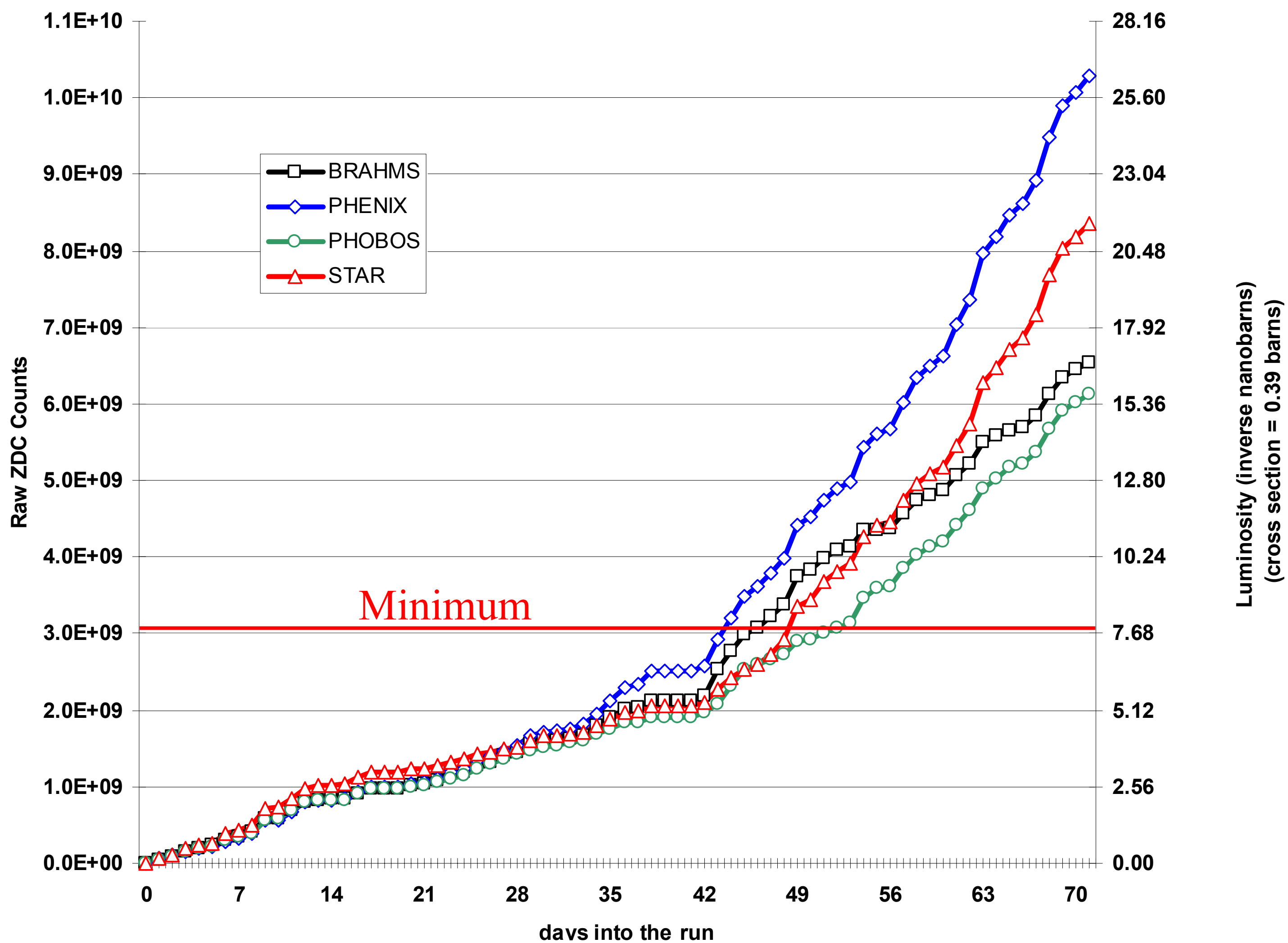
Integrated d-Au Luminosity



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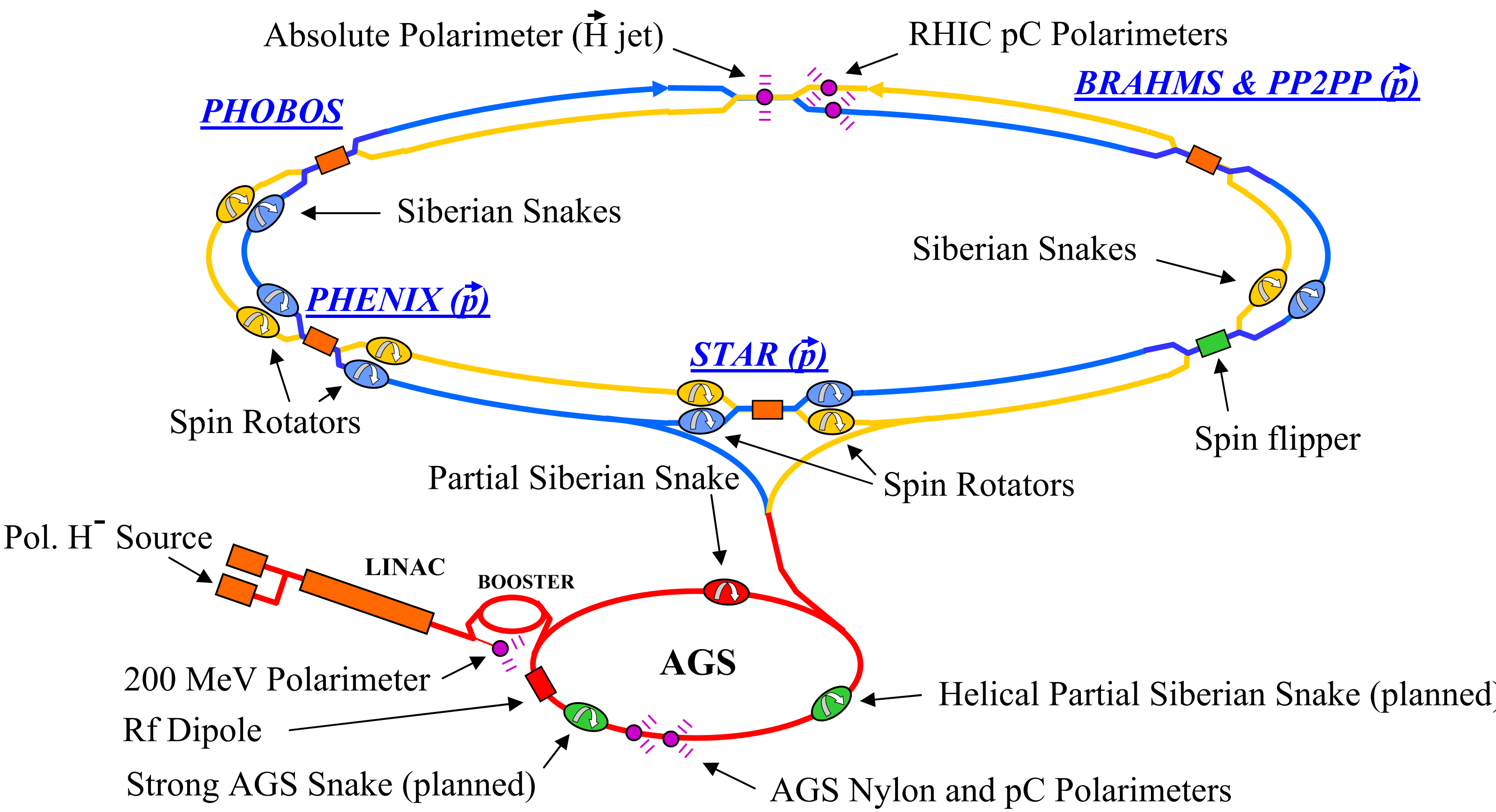
Polarized Proton Collisions in RHIC



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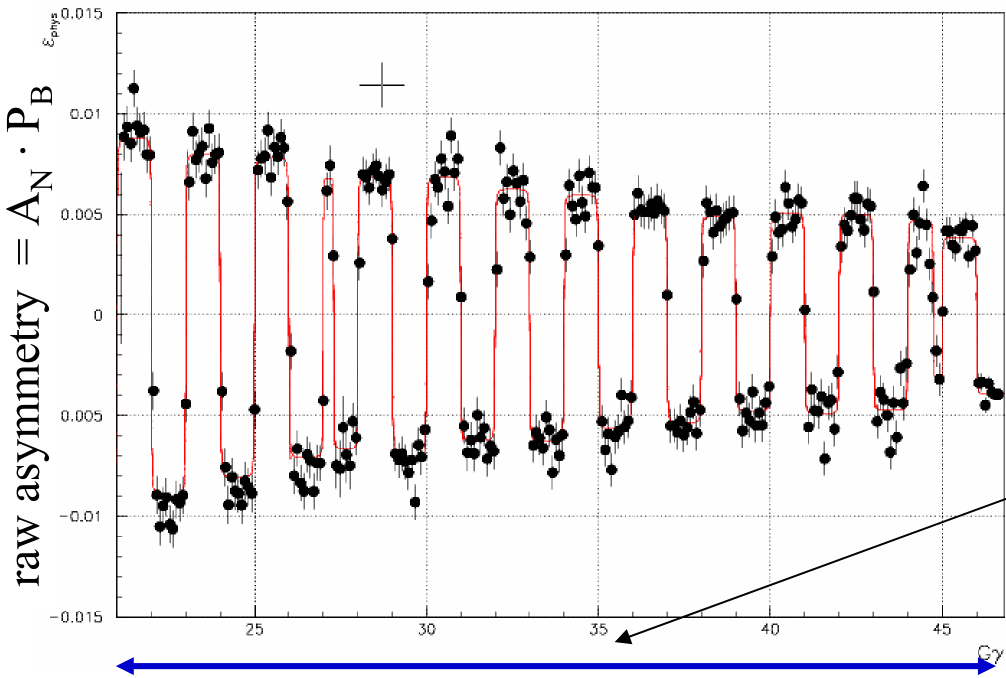
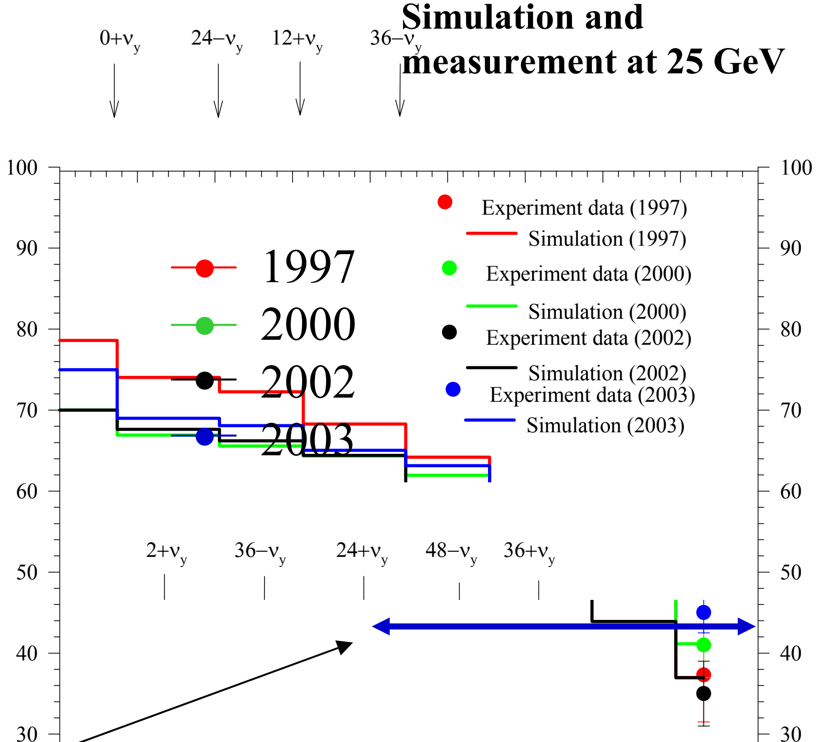
Proton polarization at the AGS

- Full spin flip at all imperfection and strong intrinsic resonances using partial Siberian snake and rf dipole
- Ramp measurement with new AGS pC CNI polarimeter:

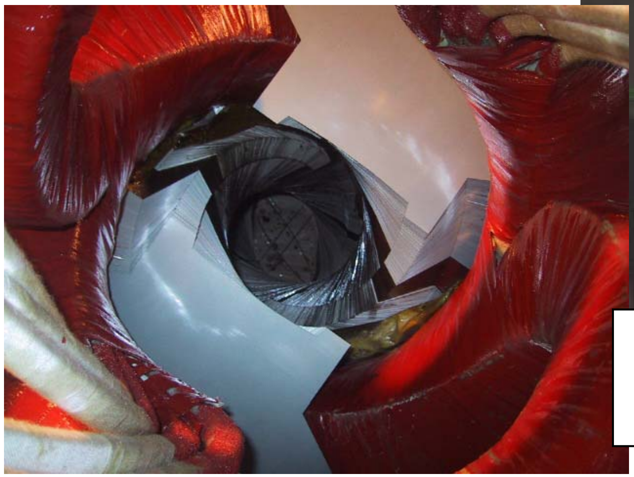


Simulation and measurement at 25 GeV



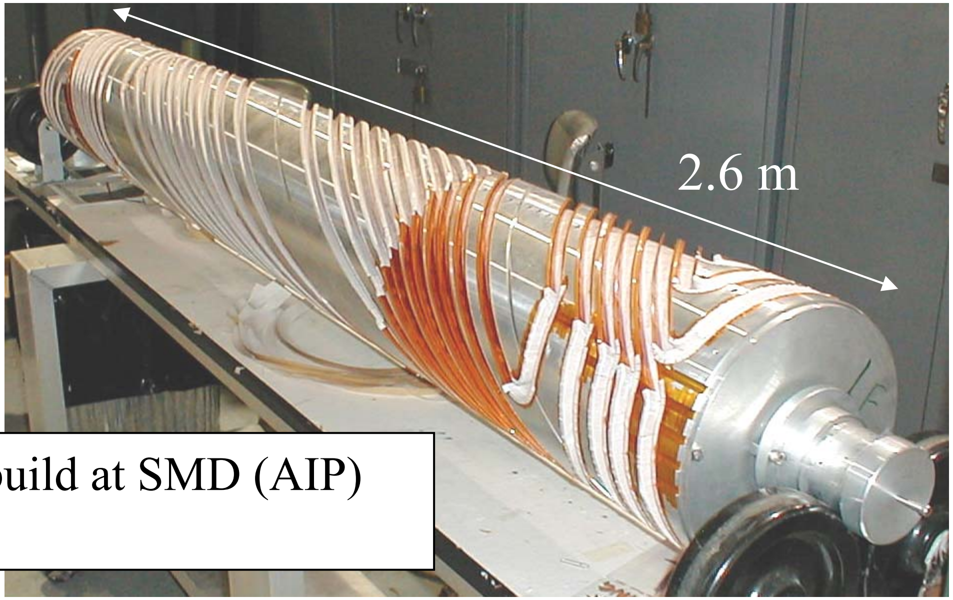
- Remaining polarization loss from coupling and weak intrinsic resonances
- New helical partial snake (RIKEN funded) will eliminate coupling res. (Install. 1/04)
- To avoid all depolarization in AGS build strong AGS helical Siberian snake! (Installation: 10/04)

New AGS helical snakes



5 % helical snake build at Tokana Industries funded by RIKEN. Installation: Jan. 2004.

- Cold strong snake eliminates all depolarizing resonances in AGS.
- Warm snake avoids polarization mismatch at AGS injection and extraction.



30% s.c. helical snake build at SMD (AIP) Installation: Oct. 2004

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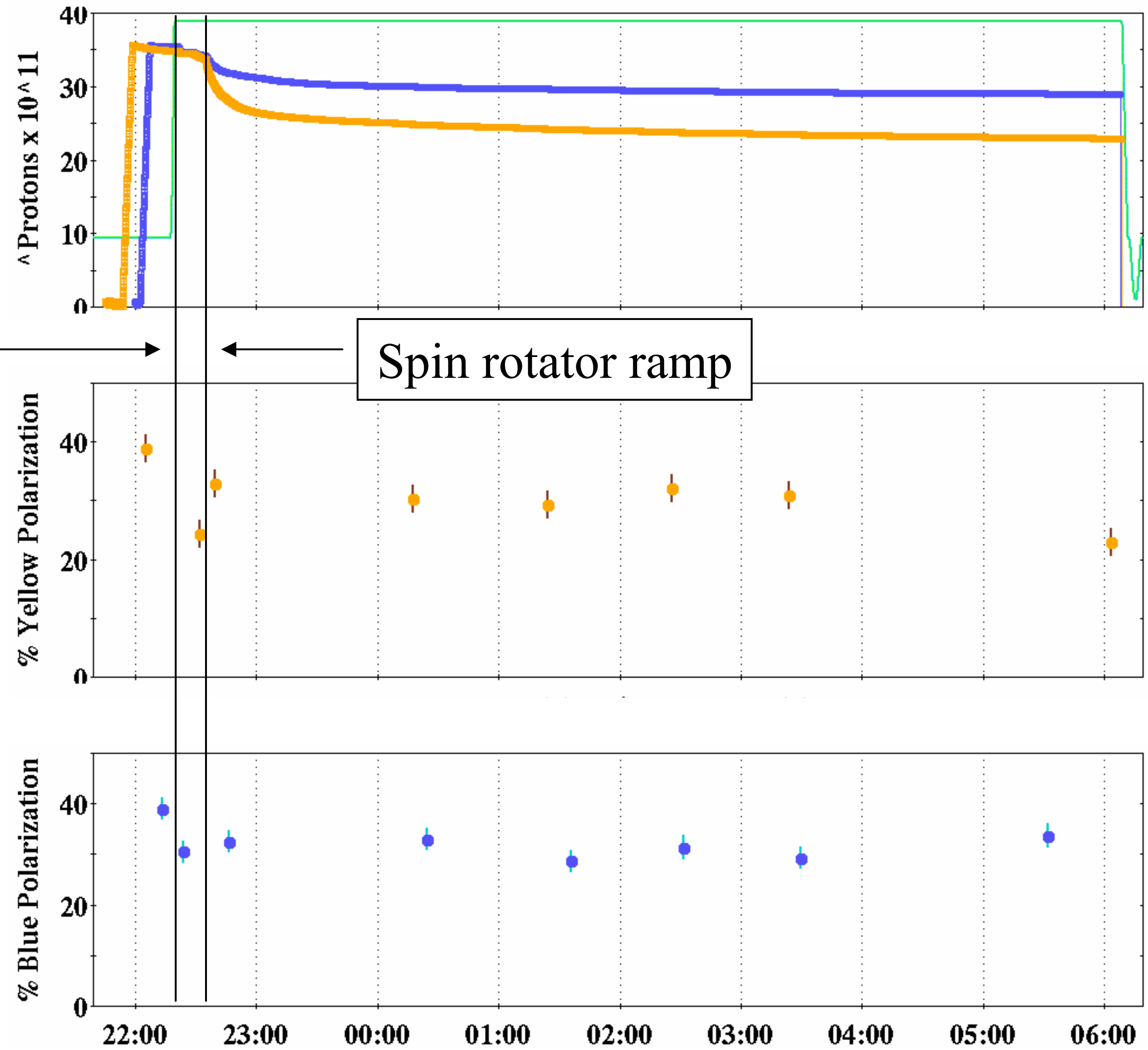
Polarization survival in RHIC (store # 3713)

Acceleration and squeeze ramp

Spin rotator ramp



Some loss during accel/squeeze ramp (Tune too close to ¼)

No loss during spin rotator ramp and during store

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Achievements during 9-week p-p run

- Source polarization ~70-75%
- AGS provided 50% peak and 40% average polarization.
- Spin rotators commissioned successfully. Longitudinal polarization for the first time at IR 6 and 8.
- One helix in 9 o'clock Yellow snake failed. Remaining helices allowed for 88% snake, which was sufficient to maintain polarization.
- Set up six different lattices (!): β* = 2m for all IRs; β* = 1m at IR 6 and 8 and 3m for IR 2 and 10; with 88% Yellow snake; with PHEINX spin rotators; with PHENIX and STAR spin rotators; β* =10m for pp2pp.
- 55 bunches per ring with 0.65 x 10^{11} p↑/bunch, emittance ~15 π, Beam polarization at store: 35% peak, 30% average
- Peak luminosity at beginning of store: ~6 × 10^{30} cm^{-2} s^{-1} at 100GeV
- Beam life-time affected by beam-beam effect. Needed to reduce number of collisions from 4 to 2. Also working point has to be accurate at 0.001 level.

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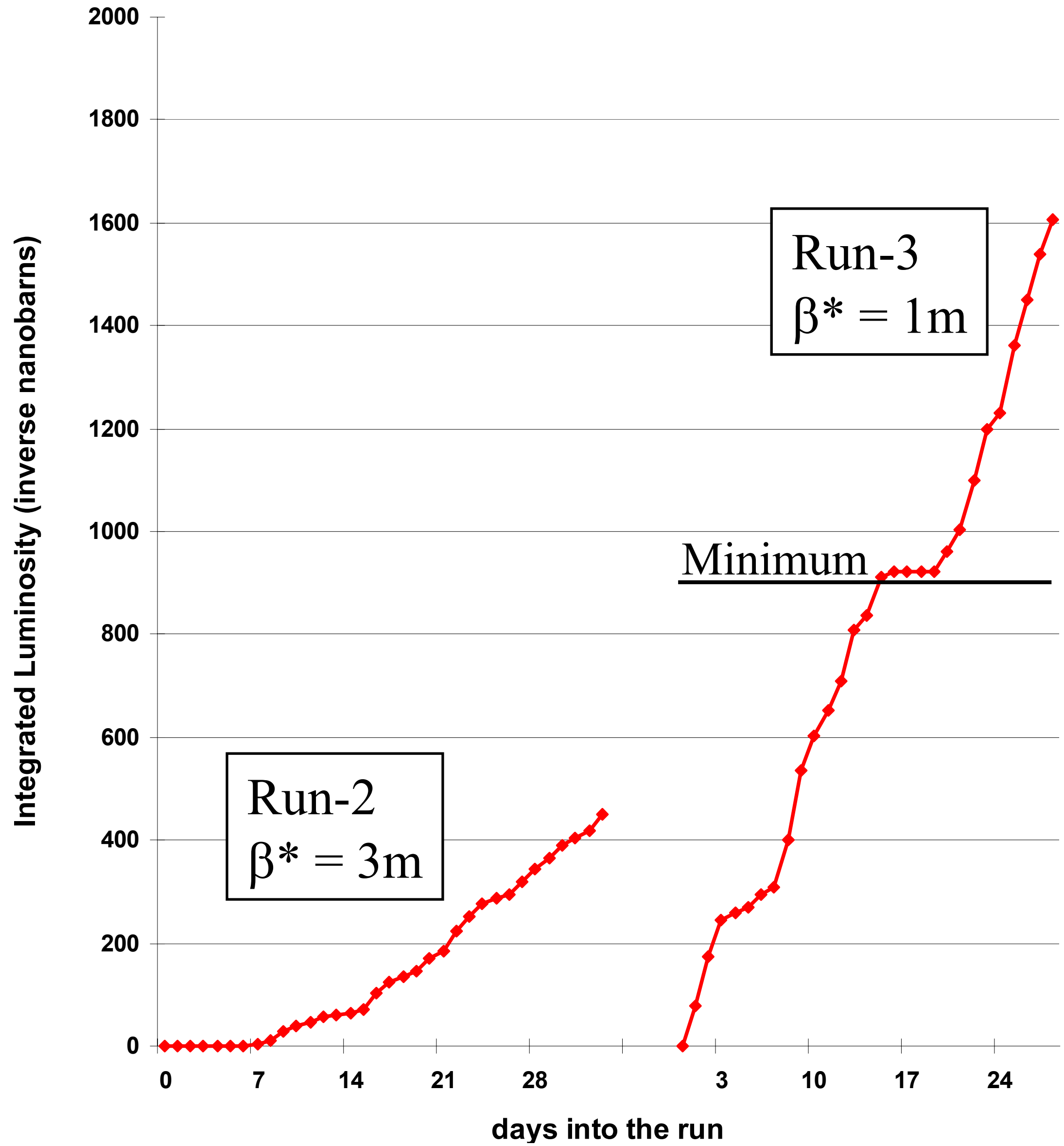
Delivered integrated p-p Luminosity

- Luminosity determined from Zero Degree Calorimeters (ZDC) that were calibrated with Vernier scans.
- Luminosities are similar for STAR and PHENIX with $\beta^* = 3$m in Run-2 and 1m in Run-3
- Days shown are from start of physics data taking.



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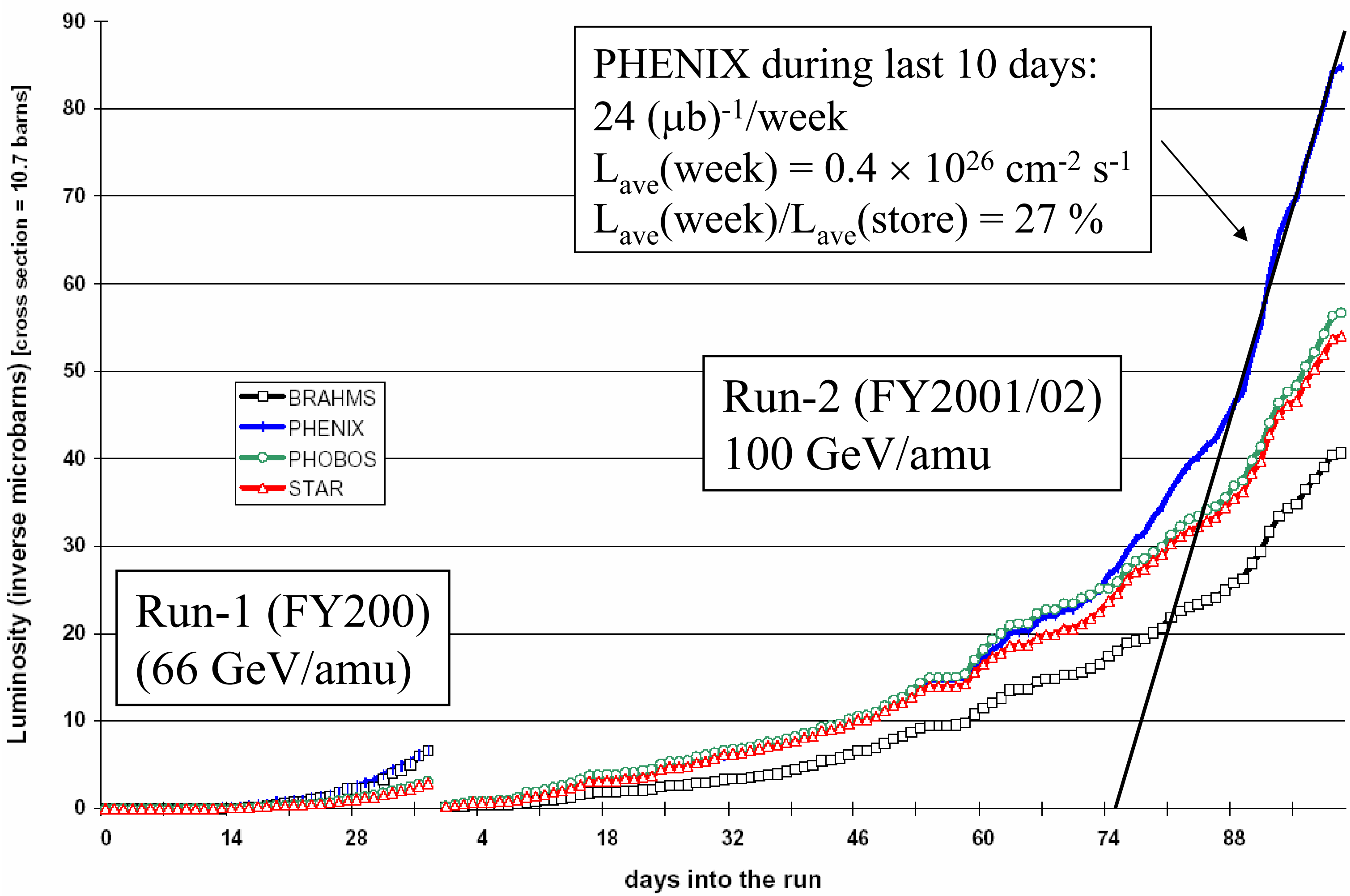
Integrated Au-Au luminosity



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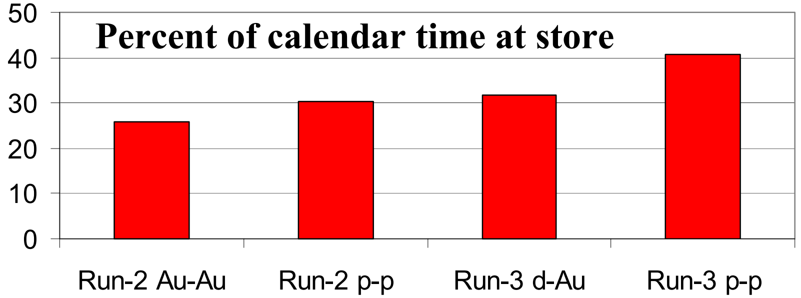
Performance summary

- Energy/beam: 100 GeV/nucl.
- Diamond length: σ = 20 cm



Mode	# bunches	Ions/bunch [10^9]	β* [m]	Emittance [$\pi\mu$m]	L_{peak} [$cm^{-2}s^{-1}$]	L_{ave}(store) [$cm^{-2}s^{-1}$]	L_{ave} (week) [$week^{-1}$]
Au-Au (*) [Run-2]	55	0.7	1	15 - 40	5×10^{26}	1.5×10^{26}	24 $(\mu b)^{-1}$
d-Au (*) [Run-3]	55	110(d), 0.7(Au)	2	15	7×10^{28}	2.0×10^{28}	4.5 $(nb)^{-1}$
p↑-p↑ (*) [Run-3]	55	70	1	20 - 30	6×10^{30}	3×10^{30}	0.6 $(pb)^{-1}$
d-Au (max. goal)	56	80(d), 1(Au)	2	20	4×10^{28}	1.6×10^{28}	4 $(nb)^{-1}$
p↑-p↑ (max. goal)	112	100	1	25	16×10^{30}	10×10^{30}	2.8$(pb)^{-1}$
Au-Au RHIC design	56	1	2	15 - 40	9×10^{26}	2×10^{26}	50 $(\mu b)^{-1}$
p-p RHIC design	56	100	2	20	5×10^{30}	4×10^{30}	1.2 $(pb)^{-1}$
p↑-p↑ RHIC spin	112	200	1	20	80×10^{30}	65×10^{30}	20$(pb)^{-1}$

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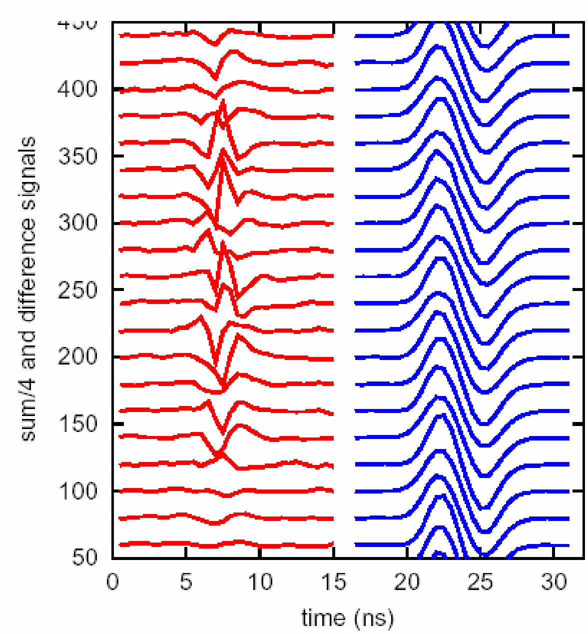
[(*) Best store or last week]

Luminosity Limitations (1)

- Injector performance (routine):
  - Au 0.7×10^9 /bunch $10\ \pi\ \mu m$ 0.3 eVs
    - additional bunch merge
  - p 0.8×10^{11} /bunch $10\ \pi\ \mu m$ 0.3 eVs   40%
  - p 2.0×10^{11} /bunch $20\ \pi\ \mu m$ 0.5 eVs   20% (?)
    - strong AGS partial snake, thinner H^- stripping foil
- Single bunch instabilities around transition:
  - Effect of vacuum chamber impedance, electron cloud (?)
  - Au: $< 0.8 \times 10^9$ ions/bunch
    - cross zero-chromaticity before transition (why?)
- Vacuum break-down due to ion desorption (?)
  - Au: $< 40 \times 10^9$ ions/ring
    - More baking, scrubbing, NEG coating
- Vacuum problem due to halo scrapping around transition (?)
  - Total accelerated charge in both rings $< 10^{13}$ e
    - More baking, scrubbing, NEG coating



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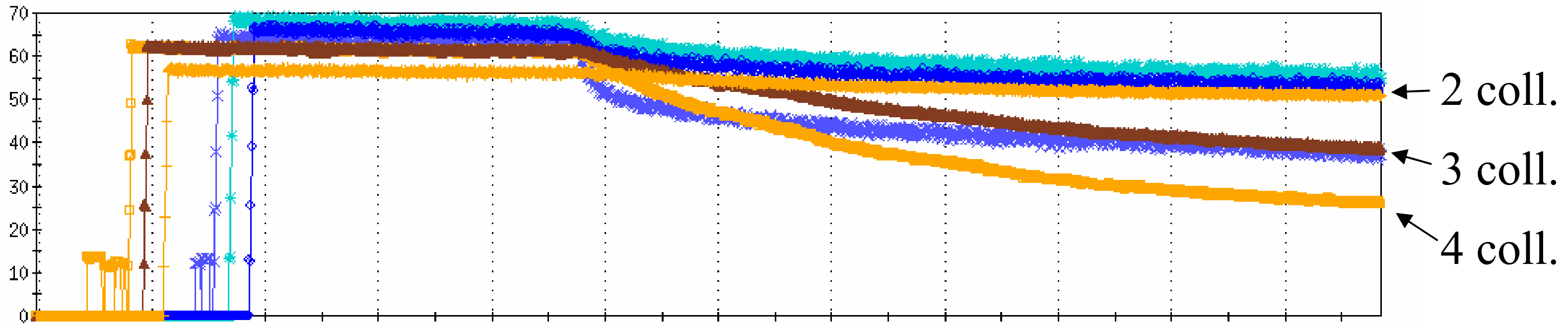
Luminosity Limitations (2)

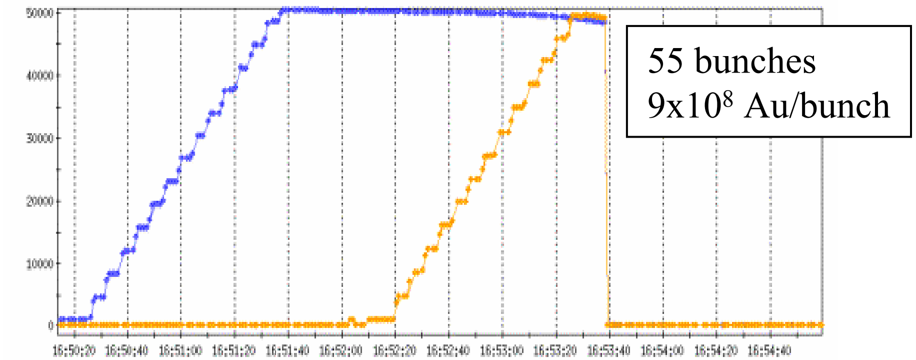
- Electron multi-pacting (electron cloud)
  - Total charge per ring less than ~ 10^{13} e, worse for 110 bunches
    - Solenoids, scrubbing, NEG coating, clearing electrodes (?)
- Beam-beam tune shift and spread
  - First strong-strong hadron collider (after ISR)
  - Limits high luminosity pp operation to two IRs
    - Non-linear corrections, better working point

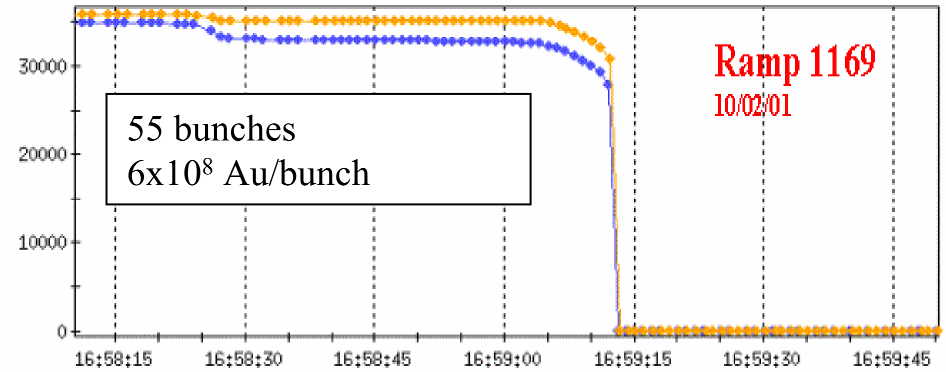


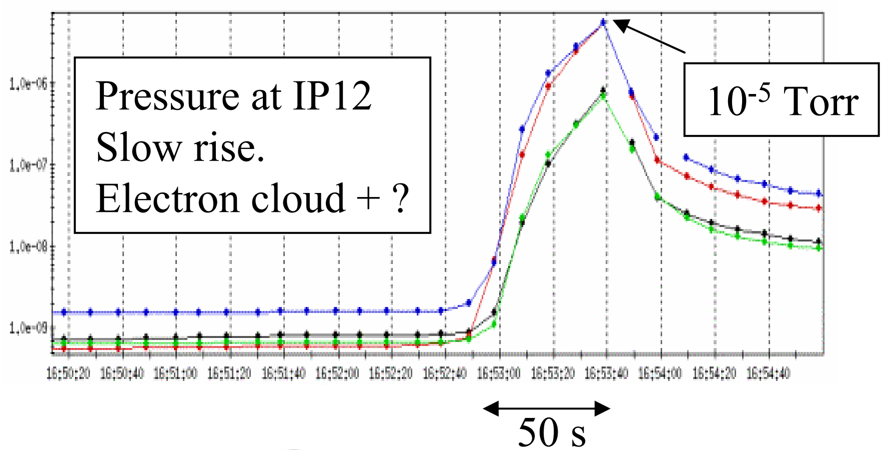
- Intra-Beam Scattering (IBS)
  - Transverse and longitudinal emittance growth
  - Eventually will need electron cooling (see below)

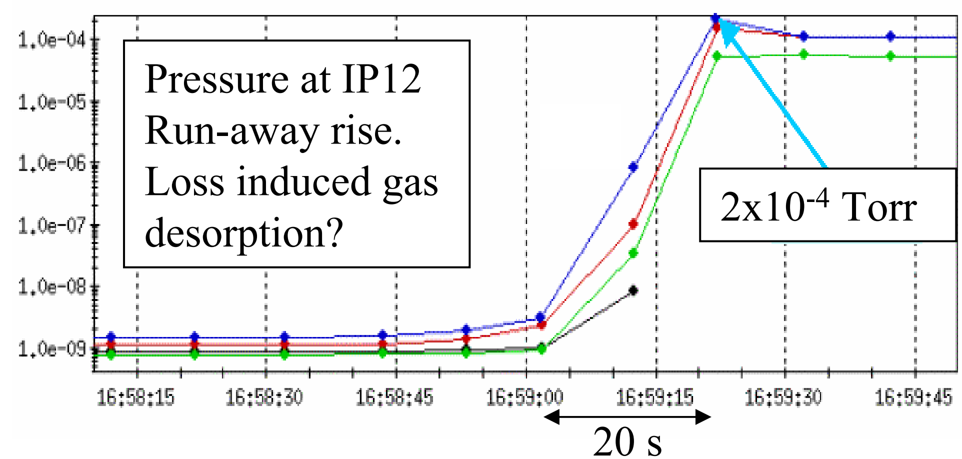
Vacuum break-down

- Mainly in warm sections that didn't have bake-out; worse with 110 bunches/ring
- Ion desorption, electron desorption, electron multi-pacting, electron cloud
- Installed electron detectors in IP12 and IP2 and solenoids for electron suppression in IP12.
- "scrubbing" with beam, NEG coated vacuum chambers









NEG coating

- NEG strips first used in TTB(BNL) and LEP(CERN)
- Non-Evaporable Getter coating: $Ti_{30}\,Zr_{30}\,V_{40}$ sputtered ~ 1 μm thick onto walls
- Developed at CERN for LHC warm sections
- Ultimate pressure < 10^{-12} Torr
- Activation: 1 h @ 250º C, 5 h @ 200º C, 24 h @ 180º C
- Secondary Electron Yield (SEY): 1.1 after activation of 2 h @ 200º C
  Strong suppression of multi-pacting (tested at SPS)
- Electron stimulated gas desorption: ~ 100 times lower than baked SS
- Ion stimulated gas desorption: ~ 10 times lower than SS (tested with 4.2 MeV/n Pb)
- **Test at RHIC: install 60 m of coated pipe, test ion desorption at Tandem**

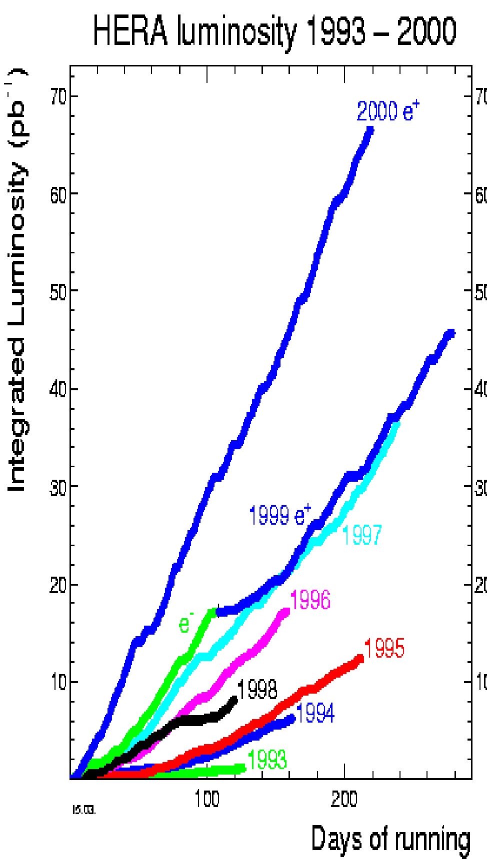
Assumptions for RHIC Collider Projections

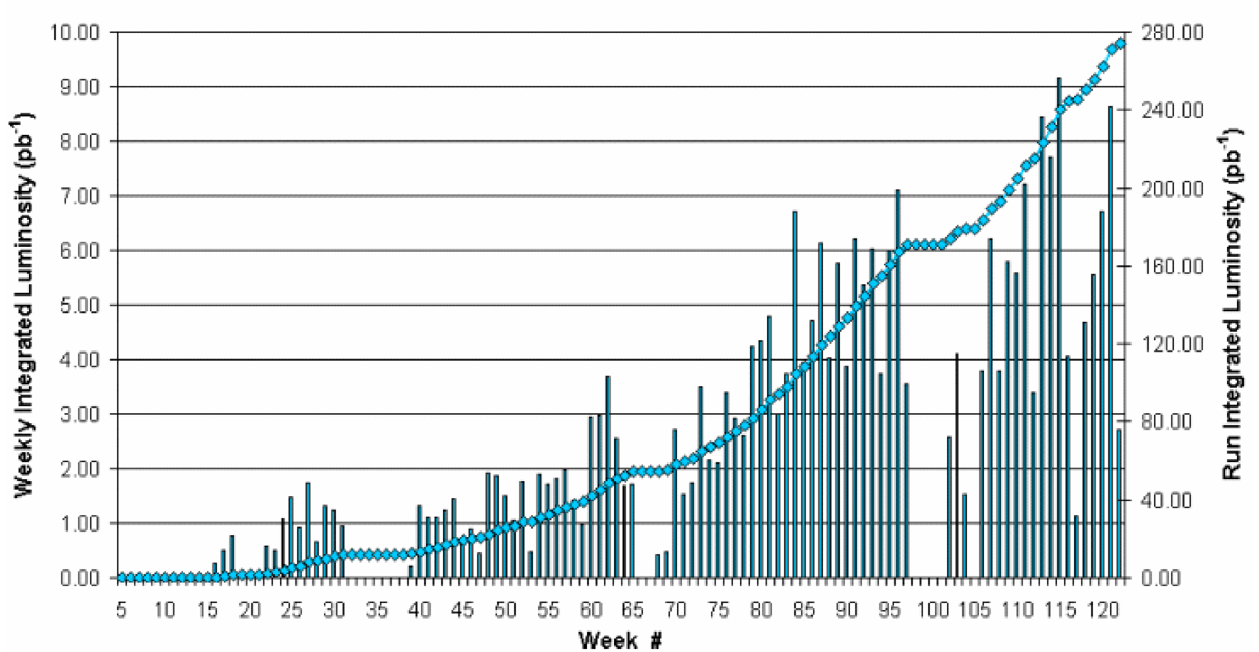
- For each mode: 2 weeks set-up and 3 weeks ramp-up
- Collisions available for trigger set-up during owl shifts of ramp-up period
- Luminosity development to continue for about an additional 14 weeks during day shifts from Monday to Friday

5-year luminosity projections:

- At least 5+14 weeks of operation of each mode for luminosity development per year
- Collisions at only two interaction regions for pp operation
- Upgrade projects need to be completed

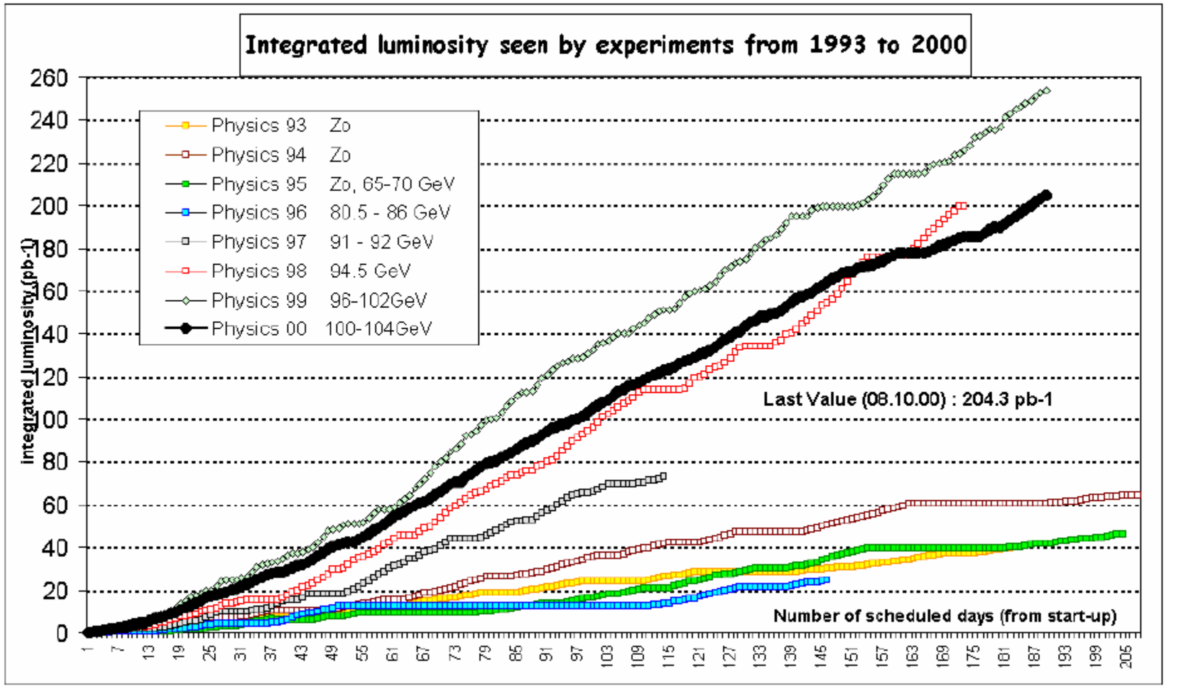
HERA and Tevatron luminosity evolutions





14 weeks

LEP luminosity evolutions



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Projected Run-4 Luminosities

Achieved:

Mode	# bunches	Ions/bunch $[10^9]$	β^* [m]	Emittance [μm]	L_{peak} $[cm^{-2}s^{-1}]$	$L_{store\ ave}$ $[cm^{-2}s^{-1}]$	L_{week}
Au-Au	55	0.6	1	15-40	3.7×10^{26}	1.5×10^{26}	24 $(\mu b)^{-1}$
(p↑-p↑)	55	70	1	20	6.0×10^{30}	3.0×10^{30}	0.6 $(pb)^{-1}$

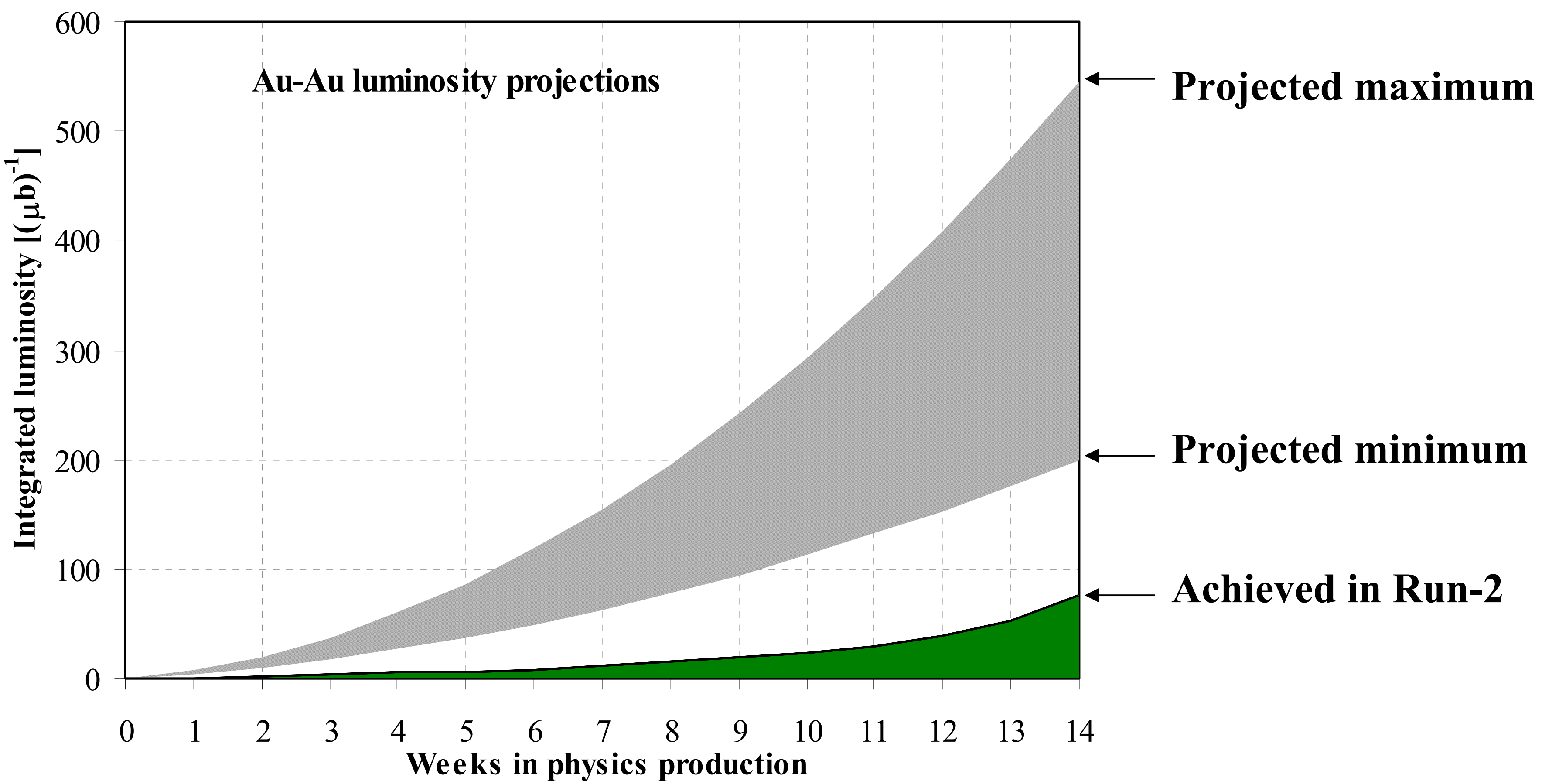
Maximum expectations:

Mode	# bunches	Ions/bunch $[10^9]$	β^* [m]	Emittance [μm]	L_{peak} $[cm^{-2}s^{-1}]$	$L_{store\ ave}$ $[cm^{-2}s^{-1}]$	L_{week}
Au-Au	56	0.9	1	15-40	12×10^{26}	3×10^{26}	70 $(\mu b)^{-1}$
(p↑-p↑)	56	100	1	20	11×10^{30}	6×10^{30}	1.4 $(pb)^{-1}$
Si-Si	56	7	1	20	5×10^{28}	2×10^{28}	5 $(nb)^{-1}$

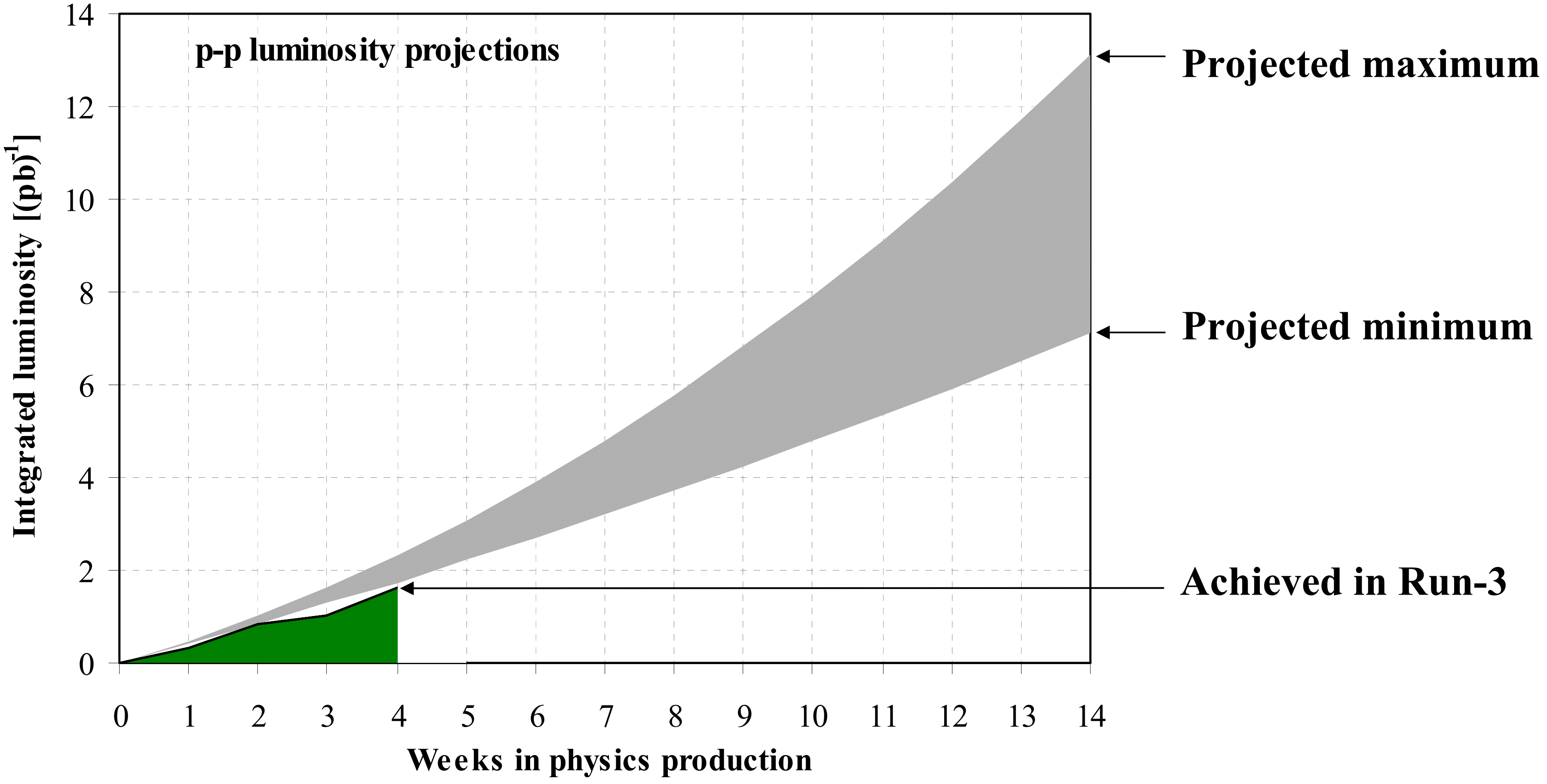
Integrated luminosity for 1 or 2 modes:

Mode	Integrated luminosity per mode			
	1 Mode (19 weeks)		2 Modes (7 weeks/mode)	
	Minimum	Maximum	Minimum	Maximum
Au-Au	320 $(\mu b)^{-1}$	895 $(\mu b)^{-1}$	63 $(\mu b)^{-1}$	155 $(\mu b)^{-1}$
(p↑-p↑)	10 $(pb)^{-1}$	20 $(pb)^{-1}$	3.2 $(pb)^{-1}$	4.8 $(pb)^{-1}$
Si-Si	?	65 $(nb)^{-1}$	?	12 $(nb)^{-1}$

Projected Run-4 Au-Au Luminosity Evolution



Projected Run-4 p - p Luminosity Evolution

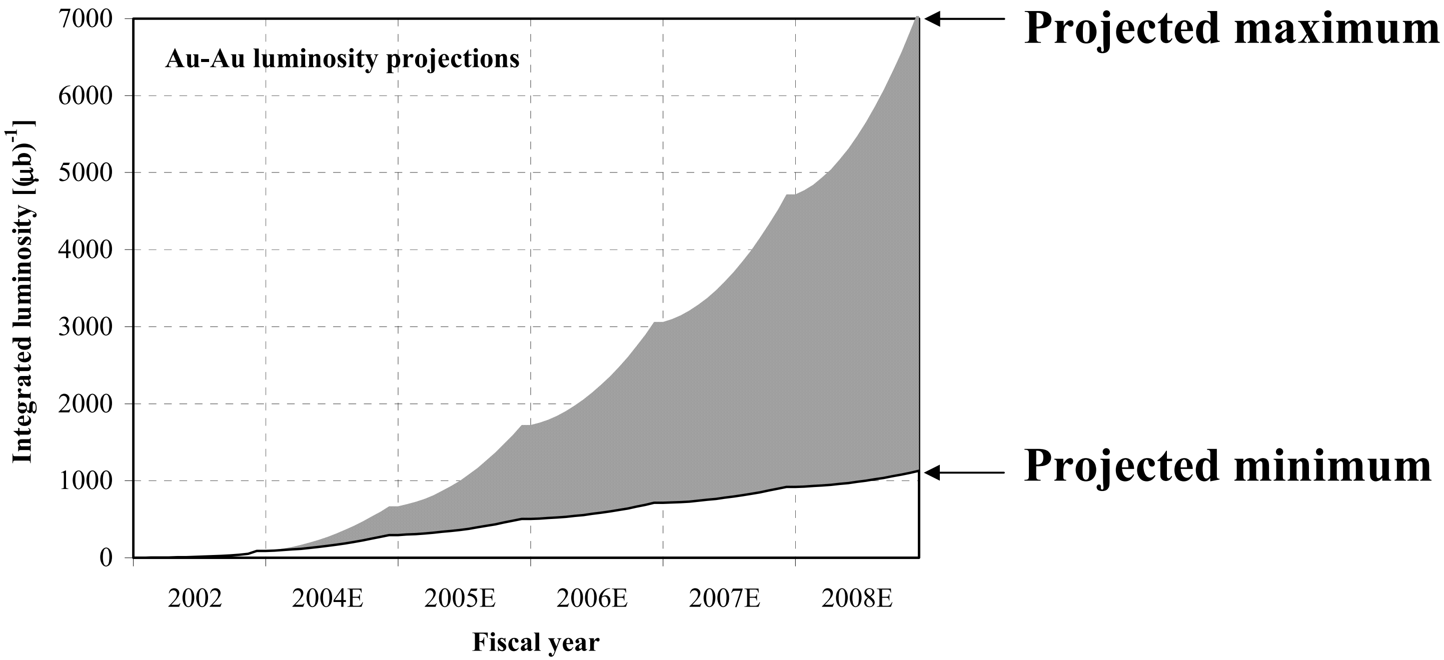


Machine goal for next 5-years

- **Enhanced RHIC luminosity (112 bunches, $\beta^* = 1$m):**
- **Au – Au: 8×10^{26} cm^{-2} s^{-1} (100 GeV/nucleon)**
- **For protons also 2×10^{11} protons/bunch (no IBS):**
- **p↑ – p↑: 6×10^{31} cm^{-2} s^{-1}; 70 % polarization (100 GeV)**
  1.5×10^{32} cm^{-2} s^{-1}; 70 % polarization (250 GeV)

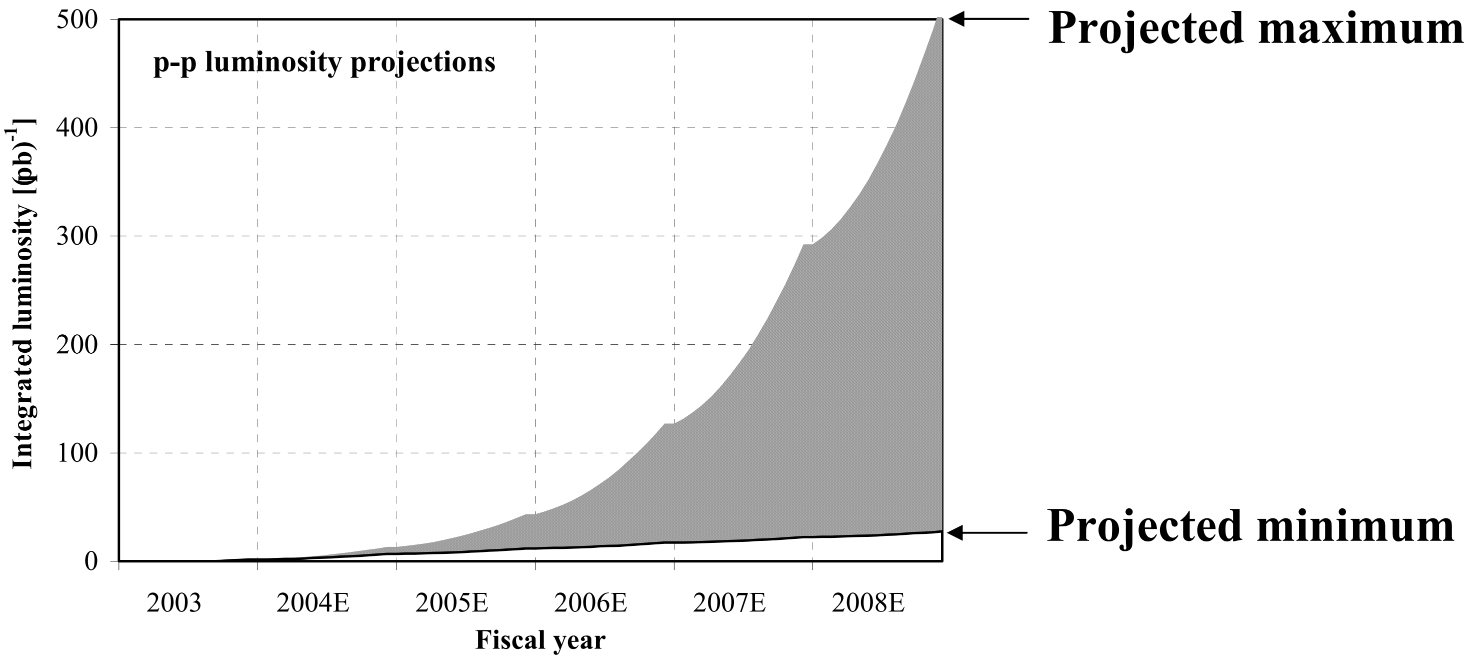
  (luminosity averaged over store delivered to 2 IRs)

Projected 5-year Au-Au Luminosity Evolution



Fiscal year		2002A	2004E	2005E	2006E	2007E	2008E
No of bunches	…	55	56	70	80	90	112
Ions/bunch, initial	10^9	0.7	0.9	1.0	1.0	1.0	1.0
Average beam current/ring	mA	38	49	69	79	89	114
β*	m	1	1	1	1	1	1
Peak luminosity	10^{26} $cm^{-2}s^{-1}$	5	12	19	21	24	32
Average store luminosity	10^{26} $cm^{-2}s^{-1}$	1.5	2.9	4.7	5.3	6.0	8.0
Time in store	%	25	40	45	50	55	60
Maximum luminosity/week	$(\mu b)^{-1}$	25	70	127	161	199	290
Minimum luminosity/week	$(\mu b)^{-1}$		25	25	25	25	25
Maximum integrated luminosity	$(\mu b)^{-1}$	89	580	1050	1340	1660	2410
Minimum integrated luminosity	$(\mu b)^{-1}$		210	210	210	210	210

Projected 5-year p - p Luminosity Evolution



Fiscal year		2002A	2003A	2004E	2005E	2006E	2007E	2008E
No of bunches	…	55	55	56	56	56	90	112
Ions/bunch, initial	10^{11}	0.7	0.7	1.0	1.4	2.0	2.0	2.0
Average beam current/ring	mA	48	48	70	98	140	225	280
β*	m	3	1	1	1	1	1	1
Peak luminosity	10^{30} cm^{-2}s^{-1}	2	6	11	22	45	72	89
Average store luminosity	10^{30} cm^{-2}s^{-1}	1.5	3	6	13	32	57	72
Time in store	…	30	41	40	45	50	55	60
Maximum luminosity/week	(pb)$^{-1}$	0.2	0.6	1.4	3.5	10	19	26
Minimum luminosity/week	(pb)$^{-1}$			0.6	0.6	0.6	0.6	0.6
Maximum integrated luminosity	(pb)$^{-1}$	0.5	1.6	12	30	84	165	224
Minimum integrated luminosity	(pb)$^{-1}$			5	5	5	5	5
AGS polarization at extraction	%	35	45	55	65	75	80	80
RHIC store polarization, peak	%	25	35	45	60	70	75	75
RHIC store polarization, average	%	15	30	40	55	65	70	70

Major RHIC Improvements

For FY2004	For FY2005	For FY2006	For FY2007	For FY2008
		RHIC injectors		
Booster low level rf upgrade			New OPPIS solenoid	EBIS test
AGS warm helical snake	AGS cold helical snake		2nd AGS cold helical snake?	
		RHIC luminosity and background		
Collimation system, 1st half	Collimation system, 2nd half			
Shielding PHENIX	Shielding STAR			
Shielding BRAHMS	Shielding PHOBOS			
NEG pipe test (60 m)	NEG pipes (300 m)	NEG pipes (400 m)		
	Solenoids?	Solenoids?		
Dedicated Landau cavities	Transverse damper system			
½ of BPM electronics to alcoves	All BPM electronics to alcoves			
	1 alcove outside ring	2 alcoves outside ring	2 alcoves outside ring	2 alcoves outside ring
Stochastic cooling 1st test	Stochastic cooling 2nd test	Stochastic cooling		
		RHIC time in store		
Orbit feed forward (ramp)	Orbit feed forward (ramp)			
Decoupling (ramp and store)	Decoupling (ramp and store)			
Gradient error correction	Gradient error correction			
AtR cooling	Tune feedback (ramp)			
Current lead ice balls elimination	Chromaticity feedback (ramp)			
Corrector PS reliability	Injection set-up			
Gap cleaning				
Abort kicker pre-fires				
Faster down-ramps				

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Summary

- Successful operation of RHIC with 100 GeV/n beams in three modes:
  - Gold – gold collisions, peak luminosity = 5×10^{26} cm^{-2} s^{-1}
  - Deuteron – gold collisions, peak luminosity = 7×10^{28} cm^{-2} s^{-1}
  - Polarized proton collisions, peak luminosity = 6×10^{30} cm^{-2} s^{-1}

- RHIC Spin data run with 100 GeV on 100 GeV polarized proton collisions and ~ 30 % polarization.

- Developed 5-year plan towards "Enhanced RHIC Luminosities"